# RAIN TYPE CLASSIFICATION FOR RAIN ATTENUATION MODELS IN TERRESTRIAL LINK

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*My humble efforts I specially dedicate to Ayah and Emak.*
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# ABSTRACT

Rain precipitation along the path from one base station to another base station is not constant due to drop size distribution of the rainfall and variation rain intensities. The signal level that propagates through rain is decreasing especially when the frequency used is above 10GHz. Rain classification is an important factor in rain attenuation studies. Rain can be classified in two broad categories which are convective rain and stratiform rain. Both categories have different effect on rain attenuation values due to different drop size distribution and different rainfall rates. However, what previous studies have not discussed is the attenuation prediction result for both stratiform and convective events. Hence, this study attempts to achieve the classification of rain by using probability method, determining 0.01% rain rate for stratiform and convective events and determining the suitable rain model that fits stratiform and convective rain. In order to choose good rain attenuation models, it is necessary to consider the link type and the experimental region. For this project, the chosen link is terrestrial link and the experimental region is tropical region. Therefore, the suitable rain models for this project are Garcia model, ITU-R 530-16 and Mello Pontes model. The duration of rain collection used for rain classification procedure is from 1996 to 1999. The percentages of time from complementary cumulative distribution function (CCDF) are used to determine which rain models suits stratiform and convective events. The result of rain classification shows that the totals numbers of stratiform and convective events are 631 events and 211 events respectively. Finding indicated that when using combined data and convective data, Mello Pontes is the most appropriate rain model to predict attenuation at terrestrial link. In addition, ITU-R 530-16, Mello Pontes model and Garcia model show good performance when using stratiform data as the three have similar attenuation values.

# ABSTRAK

Proses pemendakan hujan yang berlaku di sepanjang laluan dari satu stesen pangkalan ke satu stesen pangkalan adalah tidak serata. Ini berlaku disebabkan oleh saiz taburan hujan dan kepelbagaian intensiti hujan. Paras isyarat yang disebar melalui taburan hujan akan berkurangan terutamanya apabila frekuensi yang digunakan adalah melebihi 10GHz. Klasifikasi hujan merupakan perkara penting dalam kajian pelemahan hujan. Hujan boleh diklasifikasikan ke dalam dua kategori iaitu hujan konveksi dan hujan stratiform. Kedua-dua kategori mempunyai kesan yang berbeza terhadap pelemahan hujan kerana perbezaan saiz taburan hujan dan perbezaan kadar hujan. Walau bagaimanapun, kajian lepas tidak membincangkan hal mengenai kesan peristiwa stratiform dan konveksi keatas pelemahan hujan. Maka, kajian ini bertujuan untuk menklasifikasikan hujan dengan menggunakan kaedah kebarangkalian, menentukan kadar hujan pada 0.01% untuk peristiwa stratiform dan konveksi, dan menentukan model hujan yang sesuai dengan hujan stratiform dan konveksi. Untuk memilih model pelemahan hujan yang baik, jenis pautan dan kawasan ujikaji perlu dipertimbangkan. Untuk kajian dalam projek ini, pautan yang sesuai ialah pautan daratan dan kawasan ujikaji adalah kawasan tropika. Oleh yang demikian, model hujan yang sesuai ialah model Garcia, ITU-R 530-16 dan model Mello Pontes. Jangkamasa pengumpulan hujan yang digunakan untuk prosedur klasifikasi hujan adalah dari tahun 1996 sehingga 1999. Peratusan dari fungsi pengagihan kumulatif (CCDF) digunakan untuk menentukan model hujan yang sesuai dengan peristiwa stratiform dan konveksi. Keputusan dari prosedur klasifikasi hujan menunjukkan jumlah keseluruhan peristiwa stratiform adalah 631 dan jumlah peristiwa konveksi adalah 211. Penemuan menunjukkan bahawa apabila menggunakan data gabungan dan data konveksi, model hujan Mello Pontes adalah paling sesuai untuk menjangkakan pelemahan pada pautan terrestrial. Tambahan pula, ITU-R 530-16, model Mello Pontes dan model Garcia menunjukkan prestasi yang baik apabila menggunakan data stratiform kerana nilai pelemahan dari ketiga-tiga model adalah lebih kurang sama.

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| | | |
|---|---|---|
| $A_p$ | - | Rain attenuation exceeded at p% in dB/km |
| $A_{0.01}$ | - | Predicted attenuation exceeded for 0.01% of an average year |
| d | - | Distance path |
| $d_{eff}$ | - | Effective path length |
| $d_0$ | - | Reduction factor |
| f | - | Frequency in GHz |
| r | - | Path reduction factor |
| r(p) | - | Correction factor |
| R | - | Rain rate in mm/hr |
| $R_{0.01}$ | - | Point rainfall for 0.01% of an average year |
| $R_p$ | - | Point rainfall rate exceeded at p% |
| $R_{eff}$ | - | Effective rainfall rate |
| $\gamma$ | - | Specific attenuation in dB/km |
| $\theta$ | - | Path elevation angle |
| $\tau$ | - | Polarization tilt angle |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Terrestrial communication networking is one of the engineering fields that will continue to develop in the future due to high data rate demand. The problem with terrestrial communication is the higher frequencies used which can cause critical deficiency (Andrade & Cruz, 2015). In recent years, wireless communication devices experienced rapid growth in innovation where human populations are able to conquer a high speed services at low cost (Kuang *et al.*, 2017). The current communication networks trends are moving into higher frequency bands such as V (40/50 GHz), Ka (20/30GHz) and Ku (12/14GHz) due to spectrum congestion and increasing in data rate services (Kanellopoulos *et al.*, 2013).

Due to the increasing number of devices and the increase used of wireless communication, the radio frequency engineers are designing the propagation links that utilize higher frequencies. The benefit of using higher frequencies is more data can be send in short time, the better bandwidth available and improve system throughput (Raj & Suganthi, 2016).

The drawback of increasing frequency is the signal attenuation difficulty and the attenuation greatly depend on the frequency (Nazrul *et al.*, 2013). To cut a long story short, attenuation is a standard measure for calculating the transmission signal loss in units of decibels (dB). Signals are likely to become distorted due to attenuation increase. The reasons for signal attenuation are travel distance and surrounding conditions such as temperature and precipitation. Precipitation is further divided into five category of rain, snow, freezing rain, sleet and hail. However, rain is the largest contributor to the signal attenuation of communications system (Asen & Gibbins, 2002).

When signals are dispersed through rain precipitation, signal availability will decrease (Bogucki & Wielowieyska, 2008). This problem become worse if the frequency used exceeds 10GHz (Abdulrahman *et al.*, 2012). At higher frequencies, the sizes of raindrops are close to wavelength values thus resulting in high signal attenuation.

Signals are easily reduce in strength especially when it travels in long distances. The long distance travels could be between the Satellite and Earth station or between base station and base station. The attenuation increase as the frequency gets higher (Ojo, 2008) and when the signal propagates in the rain precipitation (Kestwal *et al.*, 2014). High intensity of rainfall will cause high attenuation (Fernando *et al.*, 2012). The propagation of signal in the rains causing the absorption and the scattering of waves by the raindrops (Ojo, 2008).

## 1.2 Background of Study

Microwave communication systems are classified into terrestrial line of sight communication and satellite communication. Terrestrial communications is a type of

Earth-based communication that covered data transmission within geographical areas. However, satellite communications is the communication between the Earth station and the space station. Today, commonly used wireless communication includes Global Positioning System (GPS), television broadcasting industry and Internet usage around the world. History of wireless communications has begun since World War I and World War II. The army then began to invent a system such as wireless telegraph in year 1913.

The important issue for data transmission between receiver and transmitter whether terrestrial communications or satellite communications are the reliability and the availability of links during rain events. Generally, rain precipitation affects the signal performance in links as it contributes largest signal loss (Yeo *et al.*, 2014). Rain attenuation model is essential tool to measure the amount of attenuation prediction in links. Many studies have been done on this issue.

The aim of this study is to determine which rain attenuation model that suits best with the local rainfall data in terrestrial line-of-sight link. There are many rain attenuation models which have been developed by experienced researchers in the previous years. Among the familiar rain attenuation models are ITU-R standard model, SAM model, Garcia model and many more (Harris, 2002). Not all rain models match to rainfall data from tropical region. This is due to the fact that both tropical and temperate regions are in two different locations which possess different characteristics of rain precipitation. The rainfall data available for this project is from a tropical area which is in Johor Bharu, Malaysia.

Rain precipitation is divided into two broad categories namely stratiform and convective (Das *et al.*, 2009) (Lang *et al.*, 2003). The difference between both rain types has different effects on attenuation of the signal. In the research of rain attenuation studies in the previous years, rain drop size (DSD) is one of the factors that influence the signal propagation. Electromagnetic waves that travels in the atmosphere are tend to accidentally come into contact with raindrops. The raindrops can absorb or scatter electromagnetic energy which will then cause rain attenuation. Signal that travel along the link may undergo and experience a signal loss. This problem becomes worse if the operating frequency used between receiver and transmitter is more than 10GHz (Ojo, 2008). Rainfall rates, frequency and drop size distribution (DSD) are the elements that dominate the link performance.

There are several techniques that can classify the rain into stratiform and convective. Rain drop size (DSD) is one of those methods used to classify rainfall. This is due to the fact that drop size distributions (Das *et al.*, 2009) are different between convective rain and stratiform rain. Other methods include convective threshold level (Lang *et al.*, 2003) and detection of bright band in radar data (Das *et al.*, 2009). Previous research used radar reflectivity for rain classification and it is based on bright band signature of the radar (Chen *et al.*, 2003). Some others example of classifying the rainfall are the Gamache-Houze technique and the Atlas-Ulbrich method (Kumar *et al.*, 2011). Disdrometer and rain gauge are two devices used to measure rainfall rate. Besides, the previous research used radar data to retrieved rainfall rates (Kumar *et al.*, 2011).

Stratiform rain has smaller rain rates thus the prediction attenuation value is much smaller than convective rain. The effect of two different rainfall types on the signal propagation in terrestrial link was observed. A result from rain classification was used in three suitable rain models. The chosen rain attenuation models for this project are ITU-R 530-16, Garcia rain model and Mello Pontes rain model.

Last but not least, the attenuation values from three models were compared with measured attenuation values from previous experiments done in Johor Bharu. It was predicted that with similar local data used in the three models, in most cases, Garcia rain model did not performs well in terms of prediction rain attenuation for both stratiform and convective events. On the other hands, Mello Pontes rain model achieve better results than ITU-R 530-16 model.

## 1.3 Problem Statement

Rain can be classified into two broad categories; convective rain and stratiform rain (Das *et al.*, 2009). Both types have different effects on the signal. To calculate the attenuation value, rain classification studies need to be done because both rain types have different climatic conditions. However, previous studies on rain attenuation do not take into account these two rain types. In general, the discussions of previous experiments only compare the prediction and measure attenuation as whole. Whereas, rainfall in any areas has a mixture of both stratiform and convective which then give different attenuation affects towards the propagation signals.

Rain intensity is one of the parameters used to differentiate the rain types in the area. The past research done states that convective events comprises of higher number of high rainfall rates (Khairolanuar *et al.*, 2015). However, the previous research of rain classification based on rain intensities states that the threshold for convective events is up until 25mm/hr (Al, 2003). Rain intensities values in temperate regions are usually less than in tropical regions due to climatic conditions of both areas are different. In the region of tropical climates, the smallest rainfall rate collected is 30mm/hr which is higher than convective threshold of temperate regions. The convective threshold method of 25mm/hr is not relevant for tropical areas. However, the process of rain classification in this project can be practiced by adopting Churchill and Houze (1984) work based on convective classification using rain rates of background average to identify the convective events. Besides that, if in one rain event contains peak rain rate more than 30mm/hr, then it is classified as convective events.

ITU-R states that Malaysia is in the category of P which is experiencing heavy rainfall (Ulaganthen *et al.*, 2017). To select the appropriate rain model, it is necessary to know whether the place of study is in temperate or tropical climate. Some of the previous developed rain prediction models are not suitable for Malaysia. This is because Malaysia is a tropical area (Kesavan *et al.*, 2013) and experiencing high rainfall rates. To choose the appropriate rain attenuation model in Malaysia, it is necessary to consider the type of rain in the area.

## 1.4 Research Objectives

This study is developed under three research objectives:

1. To classify the rain types in the experimental area into stratiform events and convective events by using probability method.

2. To determine the rainfall rate of 0.01% from the rainfall data for both stratiform and convective events.

3. To identify the suitable model that fits the local data.

## 1.5 Research Scope

Although this study was carefully planned, there existed some constraint and limitations. The first restriction was the duration of the study. Because of the time restriction, the data cannot be processed in detail. The limited length of this study may only produce several analysis of rain type and analysis of rain attenuation. Secondly, this research was conducted using rain data from 1996 until 1998. Therefore, the rain data can still be used in this study as it is not enough time to collect new rainfall data. This limitation may only produce results that relevant during that rain period. The third obstacle for this research was the procedure implemented for the rain classification. Since only rainfall rates data is obtained, the only acceptable method that can be used for this project is simple probability classification technique. Finally, this research study does not develop a new rain prediction model but used the existing models available today.

# REFERENCES

Abdulrahman, A. Y., Rahman, T. A., Rahim, S. K. A., & Islam, R. (2012). Rain attenuation predictions on terrestrial radio links :

Akuon, P. O., Afullo, T. J. O., & Member, S. (2011). Path Reduction Factor Modeling for Terrestrial Links Based on Rain Cell Growth, (September), 13–15.

Al, L. E. T. (2003). Modeling of Convective – Stratiform Precipitation Processes : Sensitivity to Partitioning Methods, 505–527.

Andrade, F. J. A., & Cruz, P. A. (2015). Evaluation of ITU-R Rain Attenuation Prediction Methods for Terrestrial Links, *0*, 12–15.

Andrade, F. J. A., Da Silva Mello, L. A. R., Pontes, M. S., & Rodrigues, M. E. C. (2012). Statistical modeling of rain attenuation in tropical terrestrial links. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, *11*(2), 296–303.

Asen, W., & Gibbins, C. J. (2002). A comparison of rain attenuation and drop size distributions measured in Chilbolton and Singapore. *Radio Science*, *37*(3), 1–15.

Badron, K., Ismail, A. F., Asnawi, A., Aminah, M., Nordin, W., Alam, A. H. M. Z., & Khan, S. (2015). Classi fi cation of Precipitation Types Detected in Malaysia.

Blum, T. (2007). *www.dbebooks.com - Free Books & magazines*. *Director*.

Bogucki, J., & Wielowieyska, E. (2008). Rain precipitation in terrestrial and satellite radio links, 67–71.

Bryant, G. H., Adimula, I., Riva, C., & Brussaard, G. (2001). Rain attenuation statistics from rain cell diameters and heights. *International Journal of Satellite Communications*, *19*(3), 263–283.

Capsoni, C., Luini, L., Paraboni, A., & Riva, C. (2006). Stratiform and convective rain discrimination deduced from local P(R). *IEEE Transactions on Antennas and Propagation*, *54*(11), 3566–3569.

Capsoni, C., Luini, L., Paraboni, A., Riva, C., & Martellucci, A. (2009). A New Prediction Model of Rain Attenuation That Separately Accounts for Stratiform and Convective Rain, *57*(1), 196–204.

Cioni, S., & Ginesi, A. (2015). DVB-S2X physical layer performance results over realistic channel models. *International Journal of Satellite Communications and Networking*, *28*(5–6), 291–315.

Das, S., Shukla, A. K., & Maitra, A. (2009). Classification of Convective and Stratiform Types of Rain and their Characteristics Features at a Tropical Location. *2009 4th International Conference on Computers and Devices for Communication (Codec 2009)*, 332–335.

Elvis, A., Danso, S., Eyra, E., David, A., Selasi, D., Melody, D., & Hakii, N. (2015). Precipitation and Rainfall Types with Their Characteristic Features, *5*(20), 89–92.

Emiliani, L. D., Agudelo, J., Gutierrez, E., Restrepo, J., & Fradique-Mendez, C. (2004). Development of rain-attenuation and rain-rate maps for satellite system design in the Ku and Ka bands in Colombia. *IEEE Antennas and Propagation Magazine*, *46*(6), 54–68.

GarcÍA-LÓPez, J. A., Hernando, J. M., & Selga, J. M. (1988). Simple Rain Attenuation Prediction Method for Satellite Radio Links. *IEEE Transactions on Antennas and Propagation*, *36*(3), 444–448.

Hou, C., Wu, Z., Lu, C., & Lin, L. (2012). Analysis and Study on the Prediction Model of Rain Attenuation in Short Path.

Islam, R. M., Abdulrahman, Y. A., & Rahman, T. A. (2012). An improved ITU-R rain attenuation prediction model over terrestrial microwave links in tropical region. *EURASIP Journal on Wireless Communications and Networking*, *2012*(1), 189.

Jong, S. L., Lam, H. Y., Din, J., & D’Amico, M. (2014). The relationship between ground wind direction and seasonal variation of rain attenuation at Ku band satellite broadcasting services. *2014 31th URSI General Assembly and Scientific Symposium, URSI GASS 2014*, 3–6.

Journal, O., & Communication, S. (2002). Online Journal of Space Communication, (2), 1–10.

Kanellopoulos, S. A., Panagopoulos, A. D., Kourogiorgas, C. I., & Kanellopoulos, J. D. (2013). Satellite and terrestrial links rain attenuation time series generator for heavy rain climatic regions. *IEEE Transactions on Antennas and Propagation*, *61*(6), 3396–3399.

Kesavan, U., Tharek, a R., & Islam, M. R. (2013). Rain Attenuation Prediction Using Frequency Scaling Technique at Tropical Region for Terrestrial Link. *Progress In Electromagnetics Research Symposium*, 191–194.

Kestwal, M. C., Joshi, S., & Garia, L. S. (2014). Prediction of rain attenuation and impact of rain in wave propagation at microwave frequency for tropical region (Uttarakhand, India). *International Journal of Microwave Science and Technology*, *2014*.

Khairolanuar, M. H., Ismail, A. F., Jusoh, A. Z., Hudaa, N., & Sobli, M. (2015). CLASSIFICATION OF RAIN TYPES FOR RAIN ATTENUATION PREDICTION METHOD IMPROVEMENT BASED ON RADAR INFORMATION IN TROPICS, *10*(16), 7202–7205.

Kuang, L., Chen, X., Jiang, C., Zhang, H., & Wu, S. (2017). DYNAMIC SPECTRUM MANAGEMENT FOR 5G Radio Resource Management in Future Terrestrial-Satellite Communication Networks, (October), 81–87.

L. S. Kumar, Y. H. Lee, J. X. Yeo, and J. T. O. (2011). Tropical Rain Classification and Estimation of Rain From Z-R (Reflectivity-Rain Rate) Relationships. *Progress In Electromagnetics Research B*, *32*(July), 107–127.

Lam, H. Y., Luini, L., Din, J., Capsoni, C., & Panagopoulos, A. D. (2010). Stratiform and convective rain discrimination for equatorial region. *Proceeding, 2010 IEEE Student Conference on Research and Development - Engineering: Innovation and Beyond, SCOReD 2010*, (SCOReD), 112–116.

Lang, S., Tao, W.-K., Simpson, J., & Ferrier, B. (2003). Modeling of Convective – Stratiform Precipitation Processes: Sensitivity to Partitioning Methods. *Journal of Advances in Modeling Earth Systems*, *42*, 505–527.

Liu, J., & Lin, G. (2011). Progress In Electromagnetics Research M, Vol. 17, 113–133, 2011, *17*(February), 113–133.

Mandeep, J. S. (2009). Slant path rain attenuation comparison of prediction models for satellite applications in Malaysia. *Journal of Geophysical Research Atmospheres*, *114*(17), 1–12.

Mello, L. S., & Pontes, M. S. (2012). Unified Method for the Prediction of Rain Attenuation in Satellite and Terrestrial Links, *11*(1), 1–14.

Mello, L. S., & Pontes, M. S. (2015). Unified method for the prediction of rain attenuation in satellite and terrestrial links Unified Method for the Prediction of Rain Attenuation in Satellite and Terrestrial Links, (September).

Nazrul, M., Nordin, H., Yih, L. E. E. C., & Mahmoudbeik, A. (2013). Analysis of Rain Attenuation Model for Ku Band in Cameron Highland , Malaysia 2 Literature Review, 287–290.

Odedina, M. O., Afullo, T. J. O., & Member, S. (2007). In South Africa Using Existing Attenuation Models.

Ojo, J. S. (2008). for Satellite Communication in Ku and Ka Bands Over Nigeria, *5*, 207–223.

Park, A. S., & Park, J. (2016). Analysis of Precipitation Characteristics over with K-Band Rain Radar Peninsular Malaysia for Satellite Propagation, 1729–1732.

Pe, N. A. (2004). Improved method for prediction of rain attenuation in terrestrial links, *40*(11), 27–28.

Penide, G., Kumar, V. V., Protat, A., & May, P. T. (2013). Statistics of Drop Size Distribution Parameters and Rain Rates for Stratiform and Convective Precipitation during the North Australian Wet Season. *Monthly Weather Review*, *141*(9), 3222–3237.

R.A.Harris. (2002). *Cost 255 Final Report*.

Rahim, S. K. A. (2011). Progress In Electromagnetics Research M, Vol. 18, 17–30, 2011, *18*(April), 17–30.

Raj, C., & Suganthi, S. (2016). Survey on Microwave frequency v Band: Characteristics and challenges. *Proceedings of the 2016 IEEE International Conference on Wireless Communications, Signal Processing and Networking, WiSPNET 2016*, 256–258.

Robert, A. N. (2000). Rain: How It Affects the Communications Link. *Via Satellite*, 1–4.

Series, P. (2015). Propagation data and prediction methods required for the design of terrestrial line-of-sight systems P Series Radiowave propagation, *16*.

Shayea, I., Rahman, T. A., Azmi, M. H., & Islam, M. R. (2018). Real Measurement Study for Rain Rate and Rain Attenuation Conducted Over 26 GHz Microwave 5G Link System in Malaysia. *IEEE Access*, *3536*(c), 1–1.

Technique, P. (1999). ANALYSIS OF EXPERIMENTAL RESULTS ON MICROWAVE PROPAGATION IN SINGAPORE ' S, *21*(6), 470–473.

Ulaganathen, K., Rahman, T. A., Rahim, S. K. A., & Islam, R. M. (2013). Review of rain attenuation studies in tropical and equatorial regions in Malaysia: An overview. *IEEE Antennas and Propagation Magazine*, *55*(1), 103–113.

Ulaganathen, K., Tharek, A. R., Islam, R. M., & Abdullah, K. (2017). Rain Attenuation for 5G network in Tropical Region ( Malaysia ) for Terrestrial Link, (Micc), 28–30.

Ulaganthen, K., Rahman, T. A. B. D., & Islam, M. R. (2017). COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION FOR RAIN RATE AND RAIN ATTENUATION FOR TROPICAL REGION : MALAYSIA, (1), 54–57.

Union, I. T. (1994). Itu-R Pn.837-1 Characteristics of Precipitation for Propagation Modelling. *Geneva*, *1*, 1–4.

Wong, C. L., Venneker, R., Uhlenbrook, S., Jamil, a. B. M., & Zhou, Y. (2009). Variability of rainfall in Peninsular Malaysia. *Hydrology and Earth System Sciences Discussions*, *6*(4), 5471–5503.

Yeo, J. X., Lee, Y. H., & Ong, J. T. (2014). Rain attenuation prediction model for satellite communications in tropical regions. *IEEE Transactions on Antennas and Propagation*, *62*(11), 5775–5781.